U.S. AIR FORCE BASIC RESEARCH IN WEAKLY IONIZED GASDYNAMICS

21-25 June 2004

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Program Manager

AFOSR/NA

Air Force Research Laboratory

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15. SUBJECT TERMS

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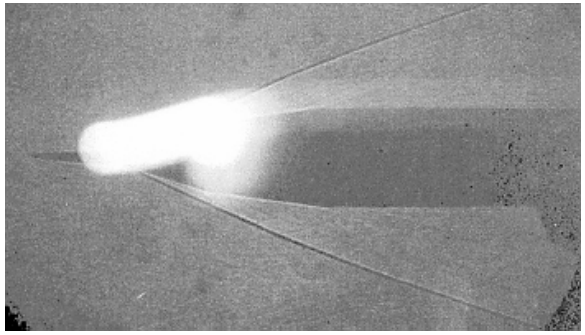
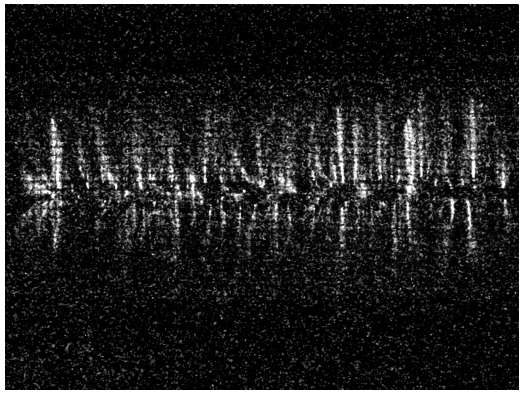
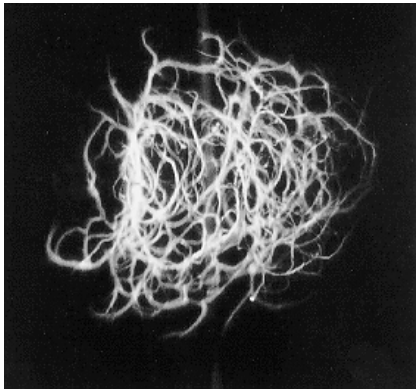
WEAKLY IONIZED GASDYNAMICS





RESEARCH OBJECTIVE: Understand, Predict, And Control Weakly Ionized Flows To Revolutionize The Performance Of Aerospace Vehicles



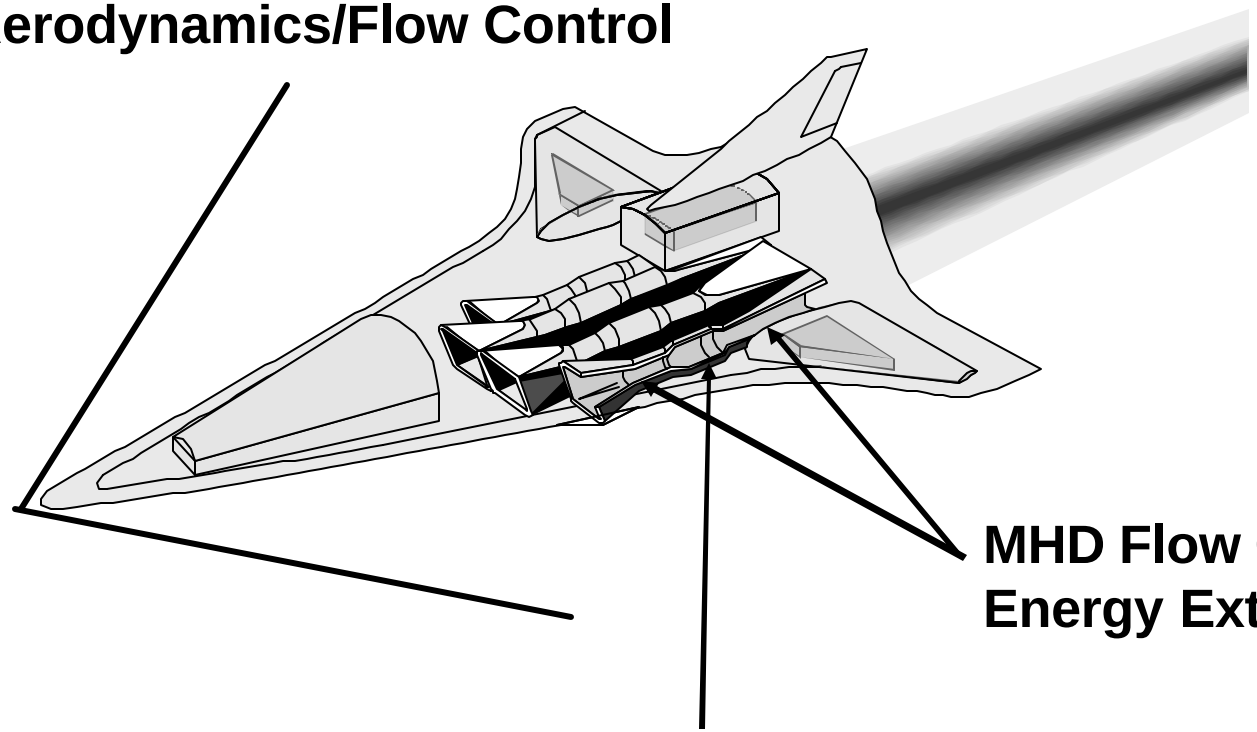
PRESENTATION OUTLINE

- Research Focus
- Research Coordination And Direction
- Selected Research Accomplishments
- Summary

WEAKLY IONIZED GASDYNAMICS

RESEARCH THRUST AREAS

Plasma Aerodynamics/Flow Control



MHD Flow Control/ Energy Extraction

Ignition/Combustion Enhancement

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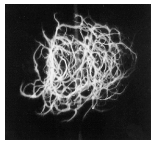
WEAKLY IONIZED GASDYNAMICS

RESEARCH MANAGEMENT

- **Semi Annual Reviews In Russia And The United States**
  - **Weakly Ionized Gas Dynamics Workshops At The American Institute Of Aeronautics And Astronautics Aerospace Sciences Meeting And Exhibit In January**
  - **Summer Workshops In Moscow And Saint Petersburg, Russia**
- **Support For Russian Research Through International Organizations**
  - **International Science And Technology Center (ISTC)**
  - **Civilian Research And Development Foundation (CRDF)**

WEAKLY IONIZED GASDYNAMICS

U.S. RESEARCH



Plasma Generation

Robert Vidmar/
Nevada, Reno

Igor Adamovich/
Ohio State

Robert Mac Cormack/
Stanford

MHD

Dennis Jacobs/
Notre Dame

Doyle Knight/
Rutgers

Norm Malmuth/
Rockwell

Datta Gaitonde/
AFRL/VA

Krishnan Mahesh/
Minnesota

Scott Morris/
Notre Dame

Aerodynamics

Bohadan Cybyk/
JHU/APL

Skip Williams/
AFRL/VS

Yiguang Ju/
Princeton

Robert Continetti/
UC San Diego

Cam Carter/
AFRL/PR

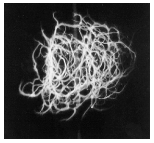
Bish Ganguly/
AFRL/PR

Martin Gundersen/
USC

Ignition/Combustion

WEAKLY IONIZED GASDYNAMICS

RUSSIAN RESEARCH



Ershov/ MSU

Plasma Generation

Esakov/ MRTI

Shibkov/ MSU

Kolesnichenko/ High Temp Inst

Timofeev/ MSU

Leonov/ High Temp Inst

Aerodynamics

Bityurin/ IVTAN

MHD

Bobachev/ Ioffe

Kuranov/ Leninetz

Klimov/ IVTAN

Starikovskii/ MIPT

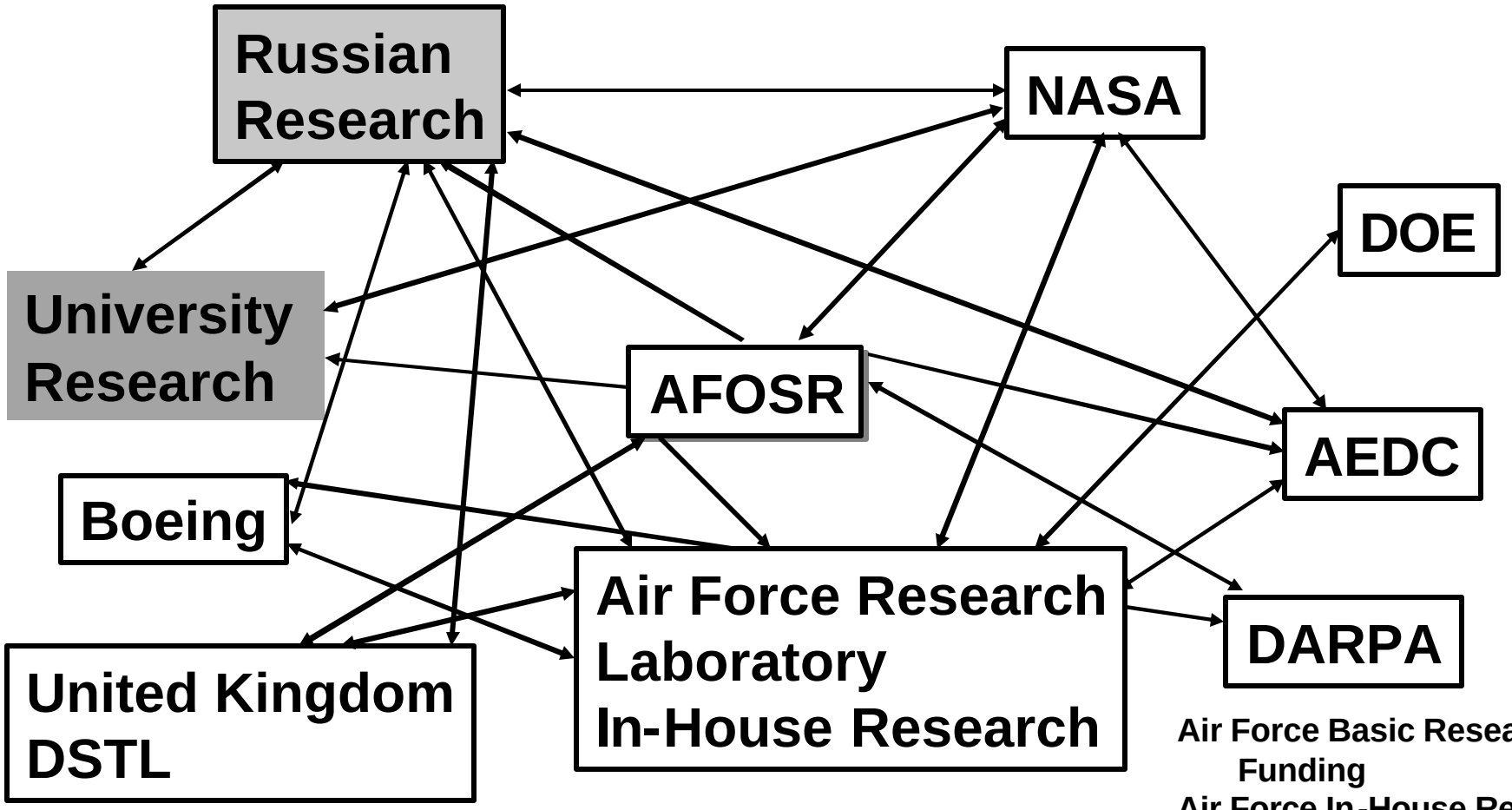
Bytchkov/ MSU

Kossyi/ Gen Phys Inst

Ignition/Combustion

WEAKLY IONIZED GASDYNAMICS

RESEARCH COLLABORATION



Air Force Basic Research Funding
Air Force In-House Research

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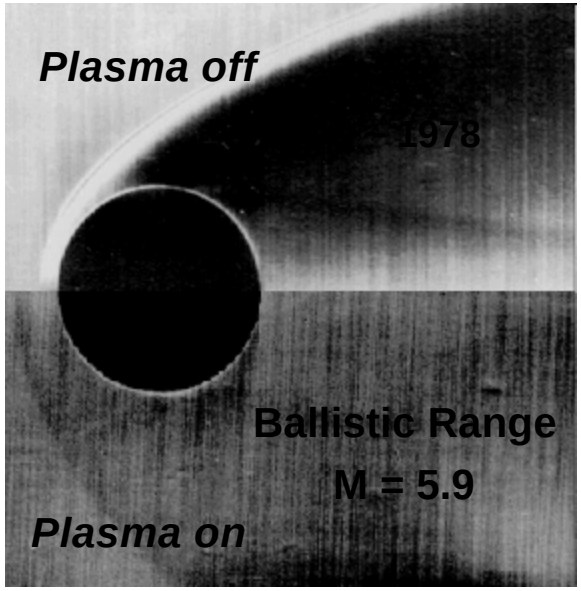
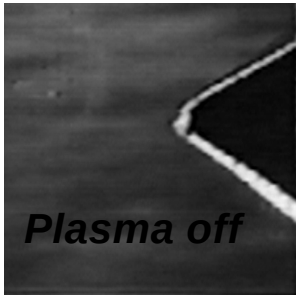
PLASMA AERODYNAMICS

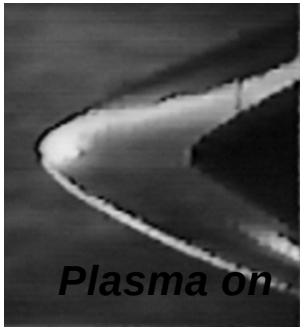
RUSSIAN EXPERIMENTS INDICATED SHOCK WAVES WERE WEAKENED IN THE PRESENCE OF WEAKLY IONIZED PLASMAS – POTENTIAL FOR DECREASED VEHICLE DRAG



SHOCK STAND-OFF DISTANCE INCREASED (INDICATING WEAKER SHOCK WAVES) IN THE PRESENCE OF PLASMA

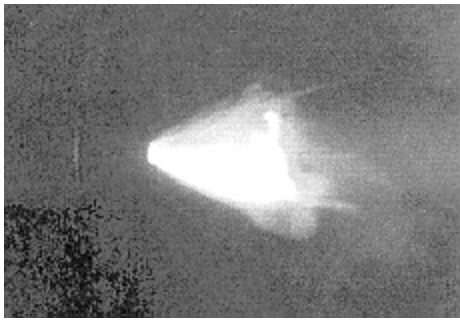


Plasma Torch
M = 4.0



TsNIIMash ~ 1997

DRAG COEFFICIENT



TIME, s

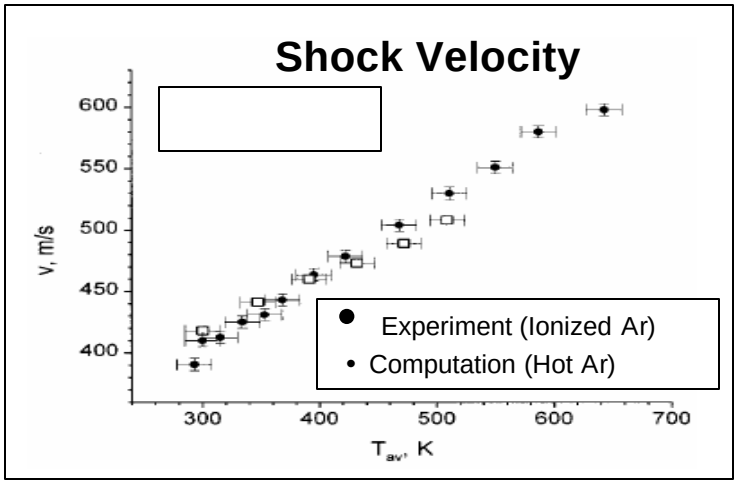
Moscow State University ~ 1998

QUESTIONS REMAINED REGARDING THE PHYSICAL MECHANISM FOR THE OBSERVED PHENOMENA

WEAKLY IONIZED GASDYNAMICS

U.S. INVESTIGATORS EXPLAIN "ANAMOLOUS" SHOCK BEHAVIOR: THERMAL EFFECT

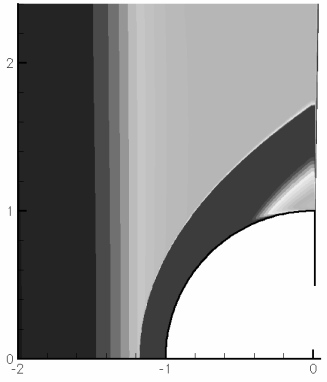
Princeton (Macheret/Miles)



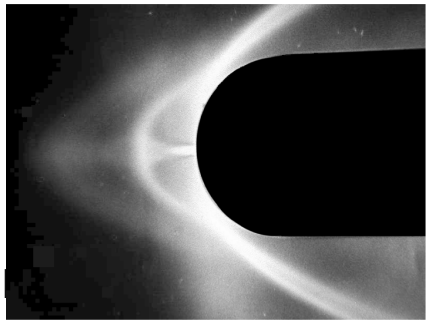
OBSERVED SHOCK-WEAKENING PHENOMENA RESULTS WHEN TEST MEDIUM IS HEATED DURING PLASMA GENERATION

- **QUESTIONS REMAIN IF THIS MAY BE EFFICIENTLY UTILIZED**

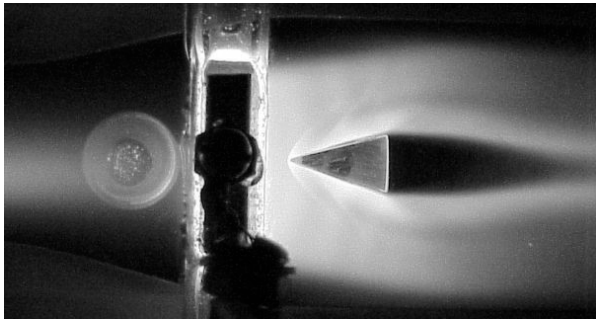
UMinn (Candler)



AFRL/VA (Shang)

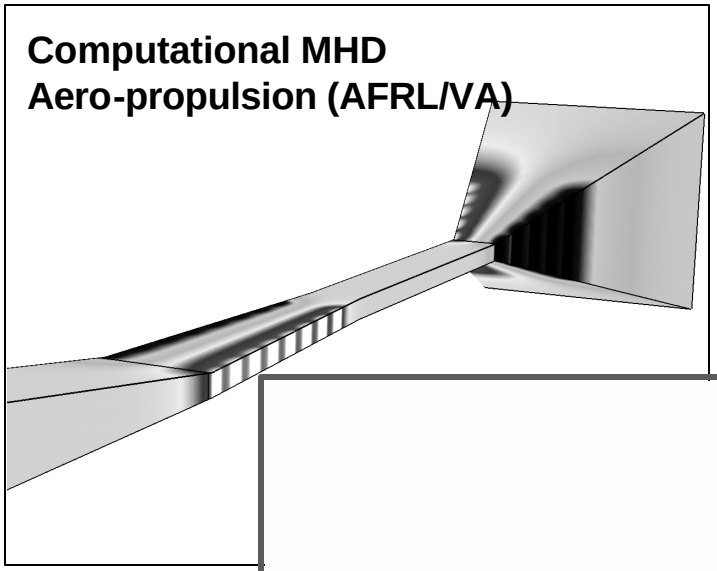


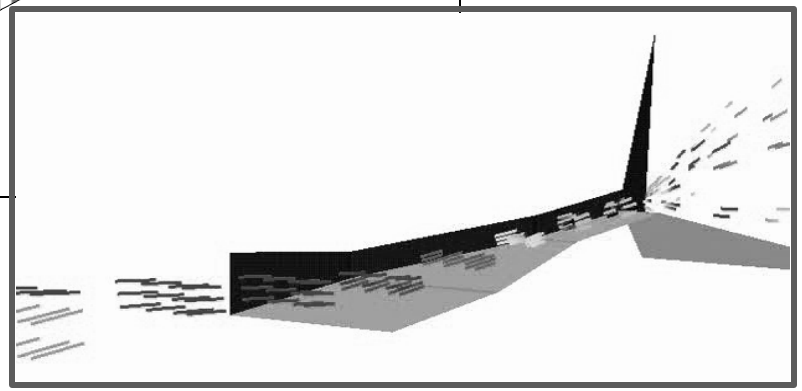
OSU (Rich/Adamovich)

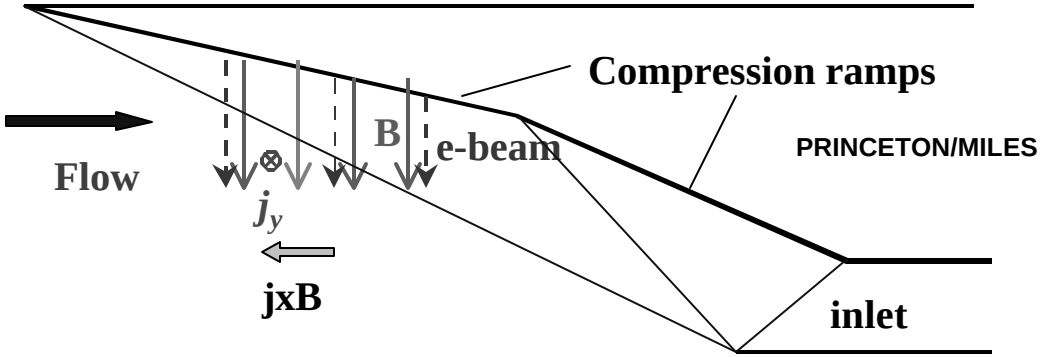


MAGNETOHYDRODYNAMICS

MAGNETOHYDRODYNAMIC (MHD) RESEARCH FOCUSES ON SCRAMJET OPTIMIZATION, POWER EXTRACTION/ADDITION



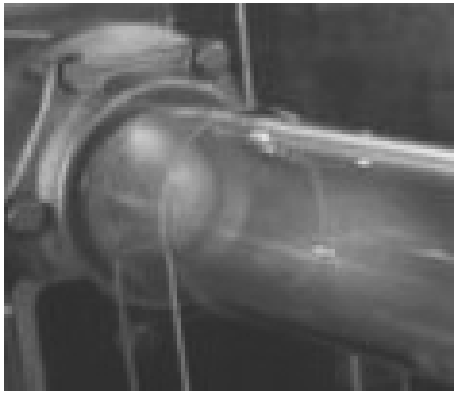




MHD USED TO DECELERATE FLOW BEFORE COMBUSTOR, ACCELERATE FLOW THROUGH NOZZLE

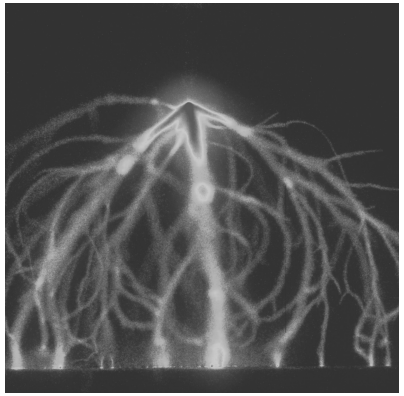
MODELING SHOWS THAT E-BEAM SUPPORTED EXTERNAL MHD DEVICE CAN BRING SHOCKS BACK TO COWL LIP AT OFF-DESIGN MACH NUMBERS WHILE GENERATING MW-SCALE NET POWER

PLASMA IGNITION ALTERNATIVES



Glow Discharge
(Adamovich/Ohio State)

dV/dt = 0



Streamer Discharge
(Gundersen/USC)

dV/dt > 1 kV/ms

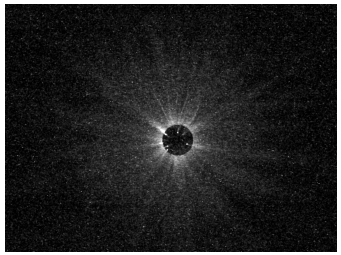
Nanosecond Discharge
(Starikovskii/MIPT)

dV/dt > 1 kV/ns

WEAKLY IONIZED GASDYNAMICS

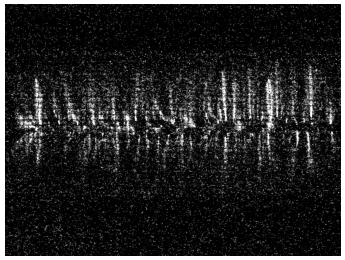
SHORT-DURATION (< 100 ns) CORONA DISCHARGE EXHIBITS SUPERIOR IGNITION CHARACTERISTICS FOR HYDROCARBON-AIR MIXTURES

- **Ignition Delay Times 1/3 Those Of Arc Igniters**

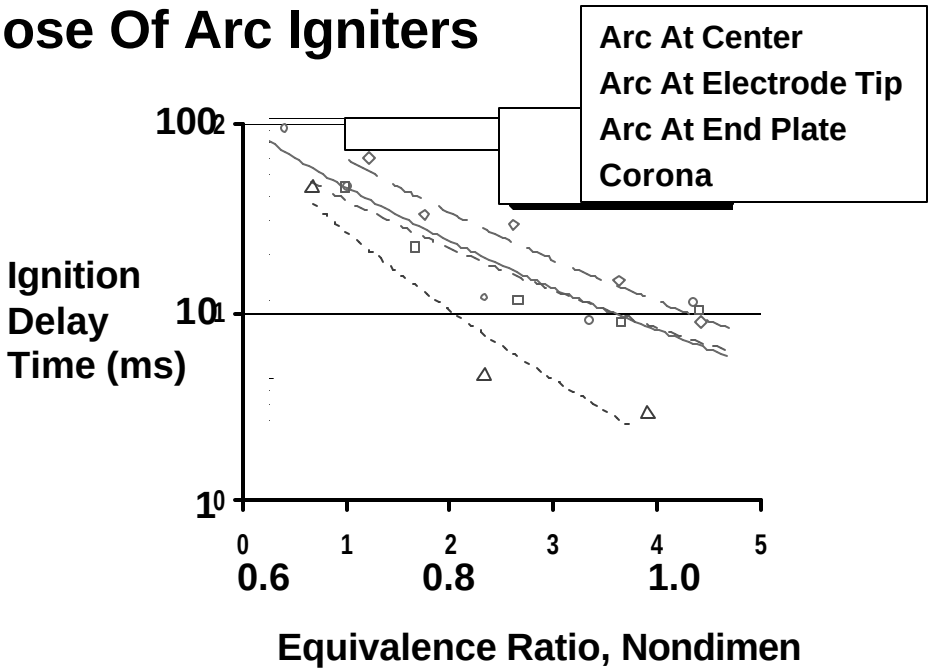


End View

Corona Discharge



Side View

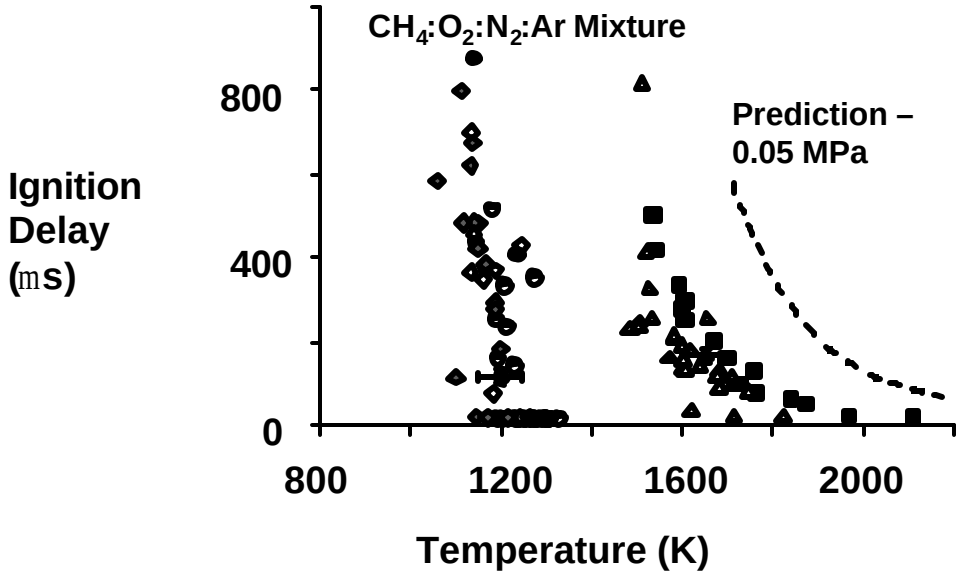


- **Corona Contains Multiple Plasma Streamers With o(10) ev Energy For Ignition**
- **Corona Discharge Ignition Based On Activation Of Radical Species Vs. Thermal Ignition For Conventional Arcs**

WEAKLY IONIZED GASDYNAMICS

SHOCK TUBE EXPERIMENTS DEMONSTRATE IGNITION DELAY REDUCTION BY FAST IONIZATION WAVES

- **Results Validate Previous Model Predictions**



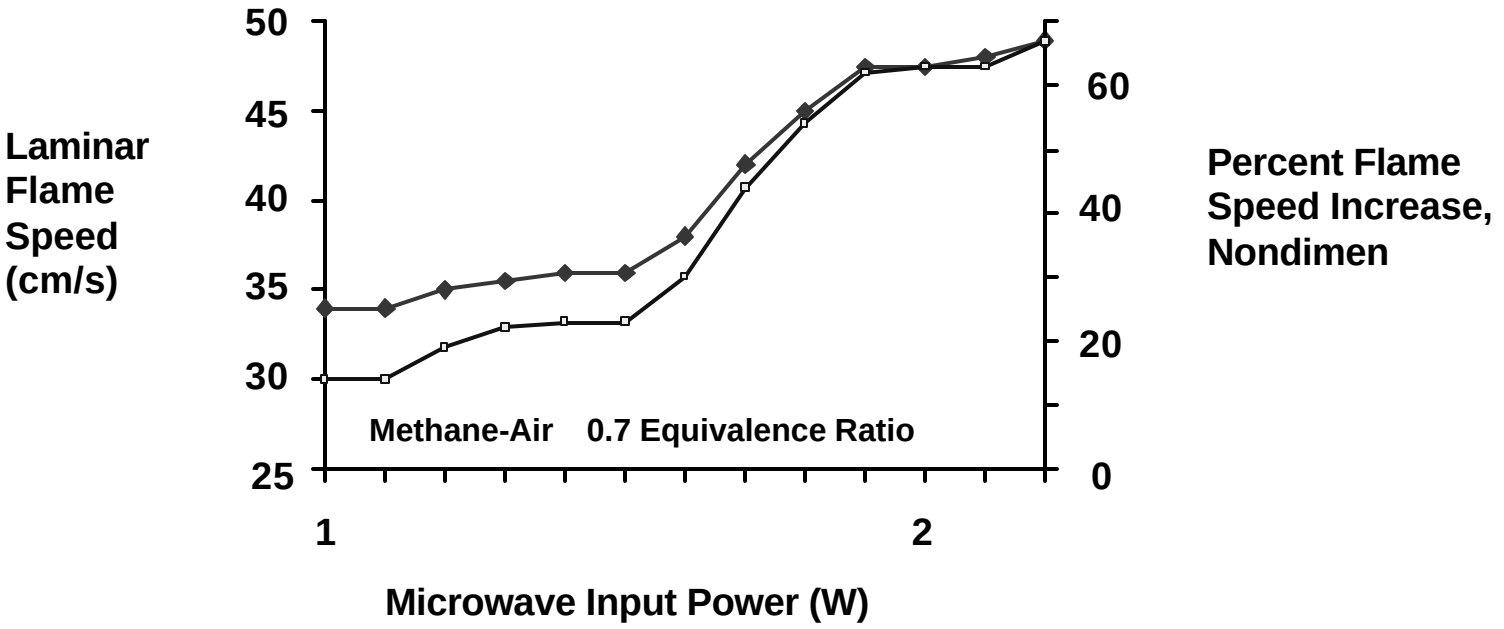
	Pressure (MPa)	FIW?	Polarity	Additive
■	0.2	No		None
△	0.2	Yes	-	He
▱	0.05	Yes	-	Air
◆	0.05	Yes	+	CO_2
◇	0.05	Yes	-	CO_2

- **Nanosecond Corona Discharge at 0.2 MPa Pressure And By Volume Nanosecond Discharge At 0.05 MPa Pressure**
- **Ignition Not Possible Without Fast Ionization Wave At 0.05 MPa Pressure**

WEAKLY IONIZED GASDYNAMICS

SIGNIFICANT ENHANCEMENT OF LAMINAR FLAME SPEED BY MICROWAVE RADIATION OBSERVED

- **Evidence For Combustor Performance Improvements By Microwave Plasmas**



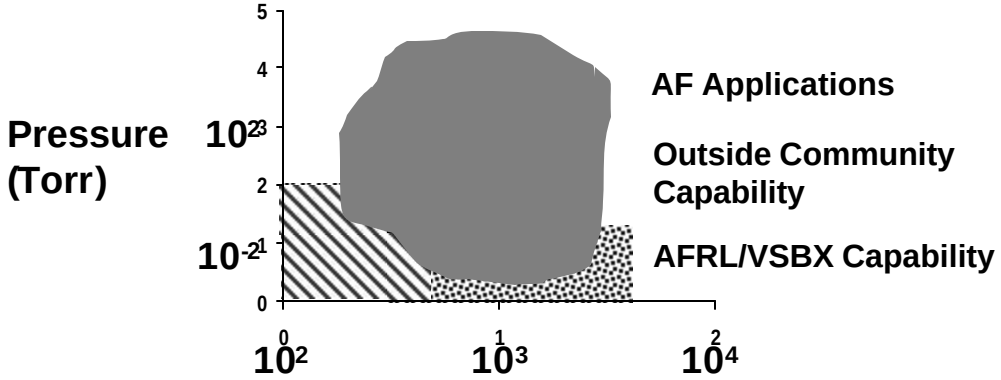
- **Plasma Strength Was Below Levels Required To Initiate Or Sustain Plasmas, Indicating That Microwaves Were Coupled To Flame-Generated Ions**
- **Applied DC Voltage Also Found To Increase Flame Speed By Unknown Mechanism**

Sullivan/Research Support Instruments
Macheret/Princeton

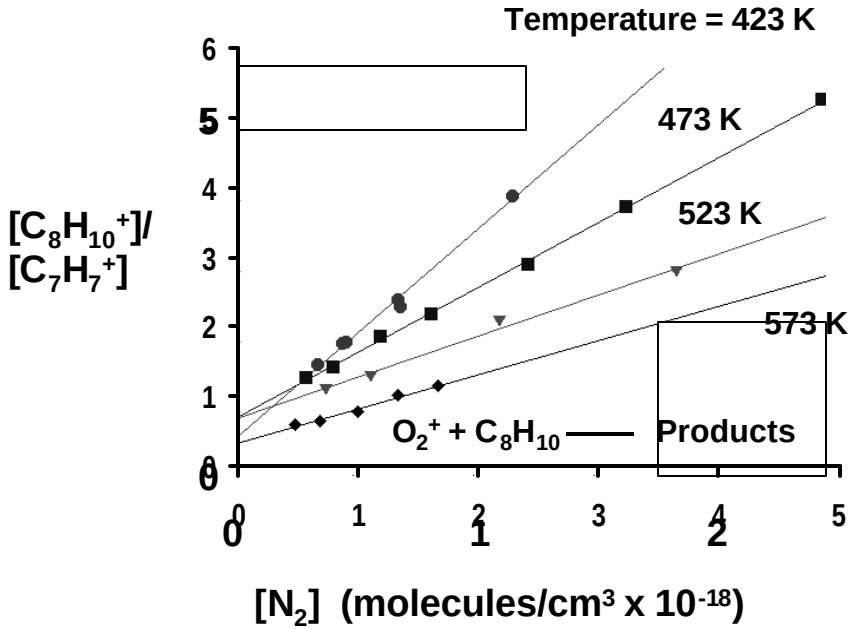
WEAKLY IONIZED GASDYNAMICS

UNIQUE FACILITIES PROVIDE REACTION RATE DATA FOR ION-MOLECULE REACTIONS

- **Critical Information For Air Plasma Chemistry And Plasma-Enhanced Combustion**



Turbulent Ion Flow Tube

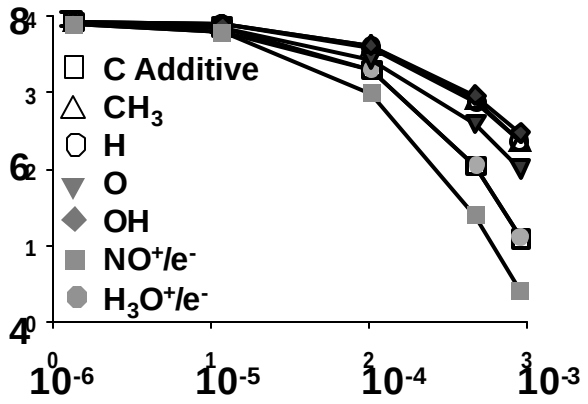


WEAKLY IONIZED GASDYNAMICS

EXPERIMENTS PROVIDE REACTION RATE DATA FOR PLASMA-ENHANCED IGNITION MODELS

- **Modeling Needed For Plasma Igniter Design**

Computed Ignition Delay Time (ms)



1% NO, 1.4% I-C_8H_{18}, 17.6% O_2, 80% Ar

T = 1000 K

P = 0.1 MPa

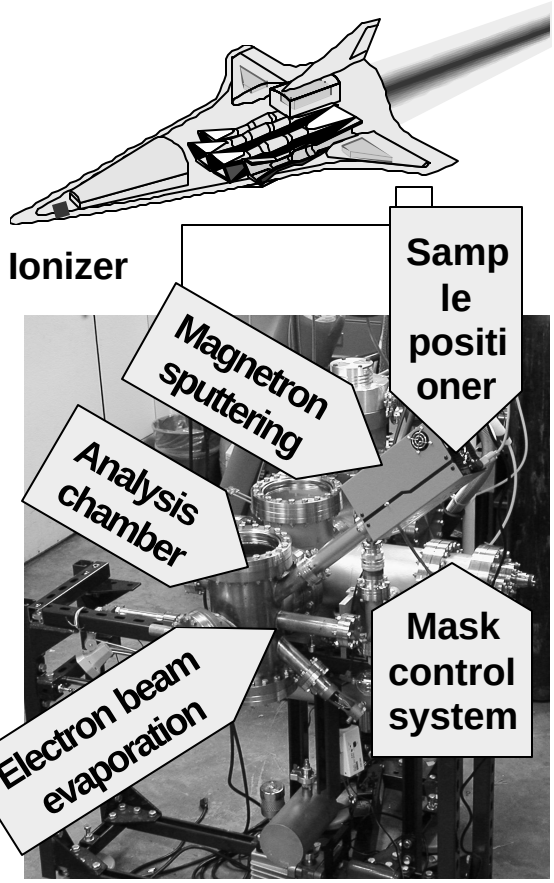
Equivalence Ratio = 1

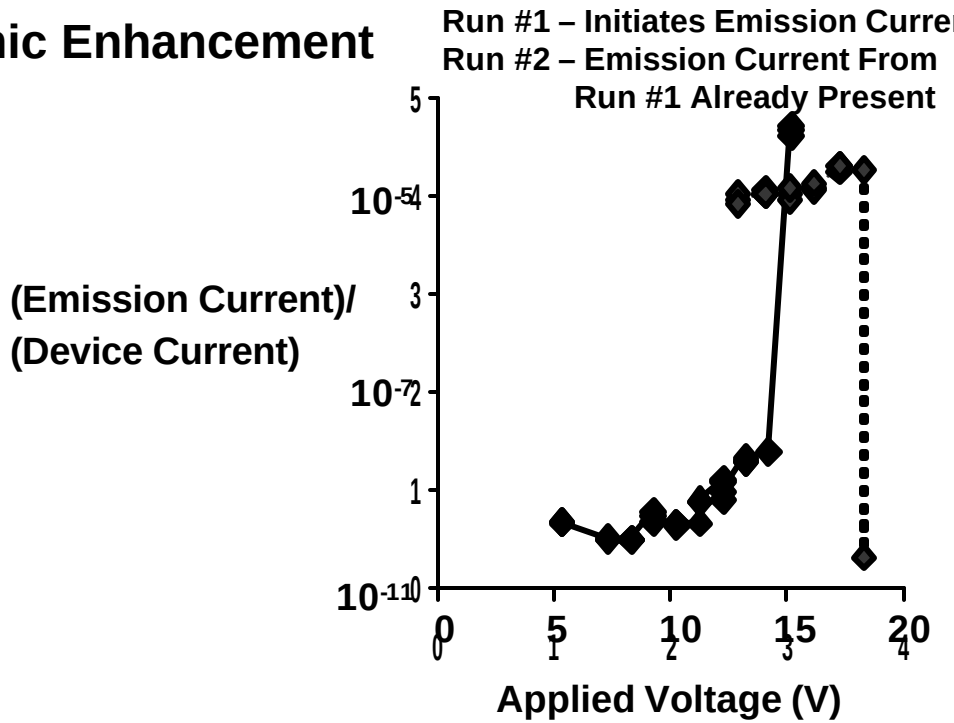
- **Supports Development Of The Lindstedt-Maurice-Leung Mechanism (1181 Reactions, 196 Species)**
- **Aids In The Selection Of JP-8 Surrogate Fuel Composition For Research**
- **Reveals Important Consequences Of Ionization (Thermal Vs. Chemical Enhancement, Fuel Vs. Air Ionization)**

WEAKLY IONIZED GASDYNAMICS

NOVEL APPARATUS PRODUCES COLD CATHODE ELECTRON EMISSION FROM NANOSTRUCTURED METAL-INSULATOR-METAL (MIM) DEVICES

- **Ion Source For Plasma Aerodynamic Enhancement**





- **MIM Devices Produced By Metal Evaporation And Magnetron Sputter Deposition**
- **Combinatorial Approach For Rapid Screening To Achieve Optimization Of MIM Structures**

PRESENTATION OUTLINE

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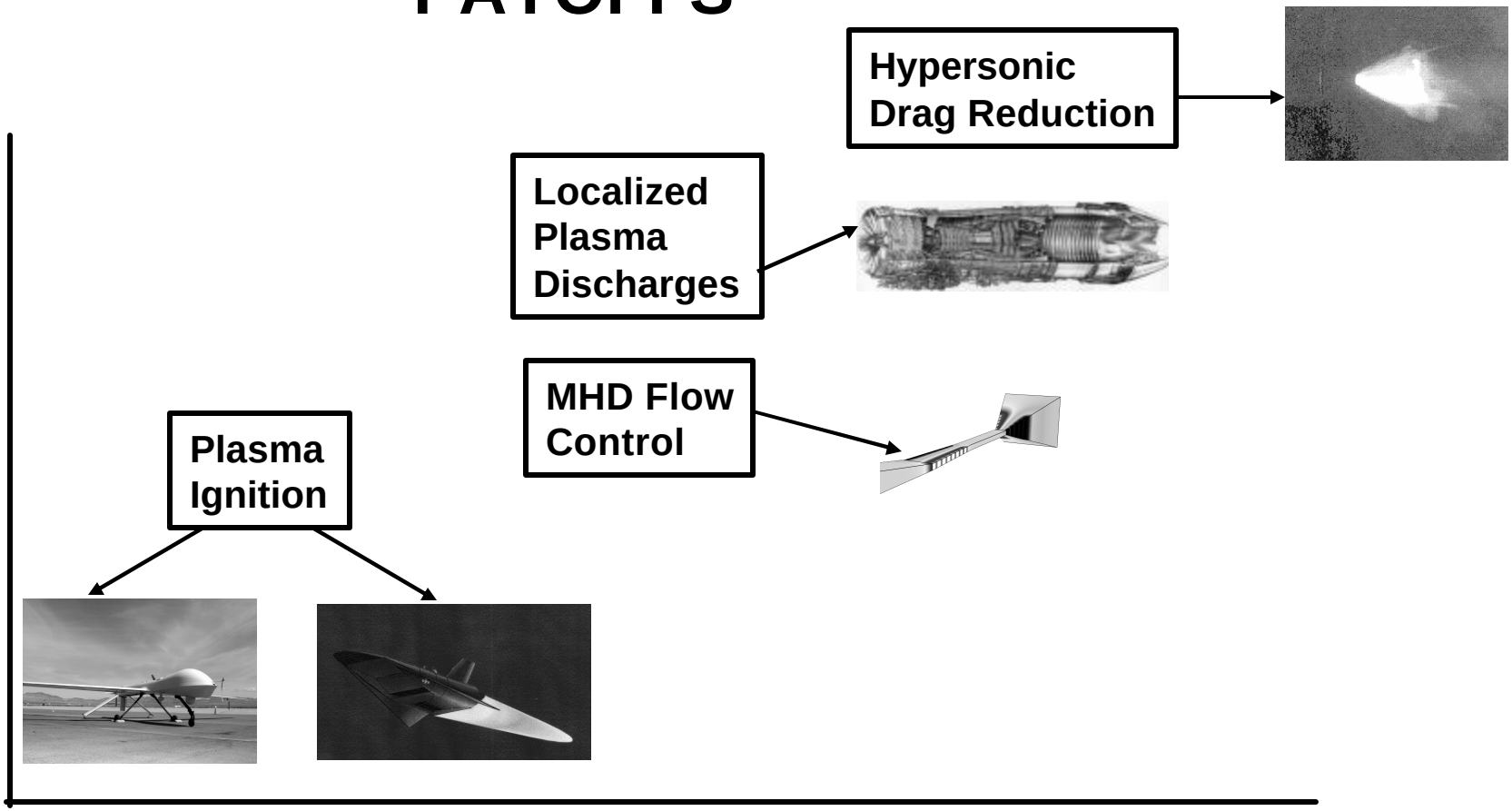
WEAKLY IONIZED GASDYNAMICS

PAYOFFS



SUMMARY

- **We Are Conducting And Coordinating International Research On Weakly Ionized Gas Dynamics**
- **Vision Of Future Technology Maturation And Transition**
- **Quality Investigators Performing World-Class Basic Research**